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A REVIEW ON HYBRID ELECTRIC VEHICLES USING VARIOUS ENERGY STORAGE: A MODERN APPLICATION OF RENEWABLE ENERGY SOURCES

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ABSTRACT

Climate change, diminishing reserves of fossil fuels, and energy security demand alternatives to our current course of energy usage and consumption. Energy storage technology has become an enabling technology for renewable energy applications and enhancing power quality in the transmission and distribution power systems. There are various types of energy storage technology are present nowadays, including compressed air energy storage(CAES), flywheel energy storage(FES), pumped hydro energy storage(PHES), battery energy storage(BES), flow battery energy storage(FBES), super conducting magnetic energy storage(SMES), super capacitor energy storage(SCES), hydrogen energy storage, synthetic fuels, and thermal energy storage(TES) and today's one of the most talked technology using these Energy storage system is Electric Vehicles. Electric vehicles are superior to internal combustion engines (ICE) in efficiency, endurance, durability, acceleration capability and simplicity. Also, they can recover some energy during regenerative braking and they are also friendly with the environment. There are now four types of electric cars: battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), conventional hybrid electric vehicles (HEVs), and fuel-cell electric vehicles (FCEVs). And there are three charging methods for electric vehicles, namely conductive, inductive, and battery exchange. This paper will show a detail study of different energy storage systems' characteristics with their suitability as a storage unit of Electric vehicle.

KEYWORDS: Energy Storage System, Electric Vehicle, Hybrid Electric Vehicle, Renewable Energy Sources

1. INTRODUCTION

Global warming has become a cause of great concern at present. The main and one of the causes of this global warming is excessive and uncontrolled use of fossil fuels. But fifty years from now there will be a time when these fossil fuel reserves will be completely exhausted and human civilization will face great problems. So, keeping in mind of next generation and human civilization, we have to increase the use of renewable energy from now. The use of this renewable energy will on the one hand eliminate the worries of the future generations and on the other hand will reduce the level of pollution in the world to a great extent. Our mother nature gives us renewable energy resources, which are solar energy, wind energy, hydro energy, tidal energy, geothermal energy, bioenergy, wave energy. The major application of these renewable energies is electricity generation, and other uses are in space, water heating and cooling and transportation.

To start using renewable energy our first step is HEV. HEV stands for Hybrid Electric Vehicle. HEVs are powered by an internal combustion engine and one or more electric motors that use energy stored in batteries. HEVs on the road today have two complementary drive systems: a gasoline engine and fuel tank and an electric motor, battery, and controls. The engine and the motor can simultaneously turn the transmission, which powers the wheels. HEVs cannot be recharged from the power grid. Their energy comes entirely from gasoline and regenerative braking. HEVs have improved fuel economy, lesser environmental impact than their ICEV counterparts, and longer range too. HEVs can be categorized by their mechanical connections as parallel, series, or parallel/series. In parallel HEVs, both the

electric motor and the engine can provide power directly to the drivetrain. In a series HEV, all the propulsion power comes from the electric motor. The engine is used only to recharge the energy storage unit. HEVs can be either mild or full hybrids

- Mild hybrids—also called micro hybrids—use a battery and electric motor to help power the vehicle and can allow the engine to shut off when the vehicle stops (such as at traffic lights or in stop-and-go traffic), further improving fuel economy. Mild hybrid systems cannot power the vehicle using electricity alone. These vehicles generally cost less than full hybrids but provide less fuel economy benefit than full hybrids
- Full hybrids have larger batteries and more powerful electric motors, which can power the vehicle for short distances and at low speeds. These vehicles cost more than mild hybrids but provide better fuel economy benefits.

Energy storage systems devices are becoming essential in power markets to increase the use of renewable energy, reduce CO2 emission. It has an important effect on overall EV systems; it

provides continuous and flexible power supply to maintain and to enhance power of EVs. Input power capability that is high enough to give good acceleration, good regenerative braking for achieving high-energy efficiency, and to accept fast charge for vehicle convenience. The potential applications of energy storage systems include utility, commercial and industrial, off-grid, and micro grid systems. Types of energy storage devices are Lead- Acid, Ni-MH, Li-ion, ZEBRA, Zinc-Air, Flywheels, Ultracapacitors, Sodium-sulfur (Na–S). The issue of energy storage arises with the need to match the demand and supply of energy to individuals.

This paper brings up about the various energy storage devices such as batteries, flywheels, ultracapacitors and its classification. And detail description about hybrid vehicle and discuss about various application of ESS in hybrid vehicles.

2. VARIOUS ENERGY STORAGE DEVICES DETAILS

Lead-acid battery: Lead-acid batteries have been used as energy sources commercially since 1860. Every internal combustion engine (ICE) vehicle is uses LA batteries as a starter and generally applied for emergency power supply. It is also use in renewable energy storage, and grid storage because of their hardness, risk free operation, limits of temperature and low cost. The battery consists of Pb as negative electrode, PbO2 as positive electrode, and H2SO4 solution as electrolyte. The electrochemical reaction takes place in Lead-acid battery as

$$Pb + PbO_2 + 2H_2SO_4 \rightarrow PbSO_4 + 2H_2O \qquad (1)$$

Lead acid battery cell also consists of spongy lead as the negative active material, lead dioxide as the positive active material, which are immersed in diluted sulfuric acid electrolyte, and lead as the current collector. At the time of discharge, lead sulfate is being produced on both electrodes. If the batteries are over discharged or kept at a discharged state, the sulfate crystals become larger and are more difficult to break up during recharge. In addition, the large lead sulfite crystals detach the active material from the collector plates. The hydrogen is produce at the positive electrode. Due to the production of hydrogen lead acid batteries suffer from water loss during overcharge. To extinguish this problem sometimes distilled water is added to submerge lead acid batteries.

Lead-acid battery is offered in two different types:

1. It is the inexpensive and mostly used in automotive and industrial applications known as the submerged type.
2. It is mostly used in power supplies and stand-alone power supplies for remote areas, known as the sealed type or valve-regulated lead-acid (VRLA).

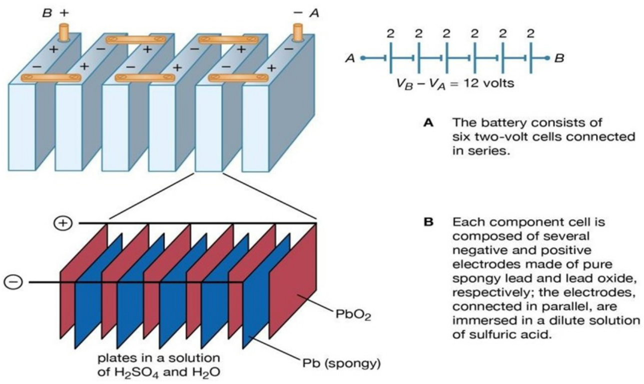

Fig.1.1: Inside configuration of Lead-Acid battery

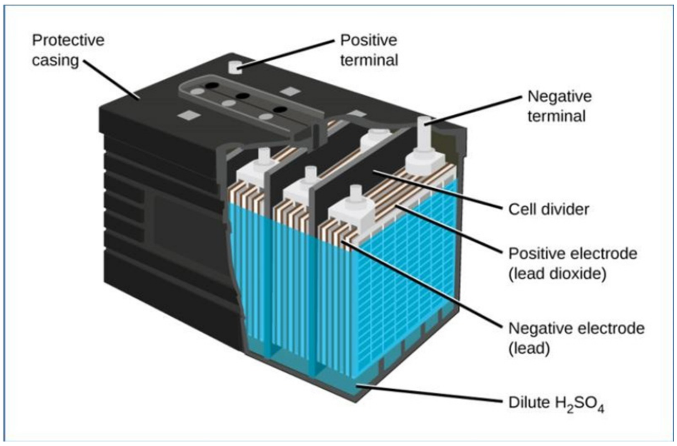

Fig.1.2: Construction of Lead-Acid battery

Li-ion battery: In all metals, the lightest metal is Lithium. It has the greatest electrochemical potential. And it's provides the largest energy per unit mass per weight. In lithium-ion (Li-ion) batteries, the lithium ions move between the anode and cathode to produce a current flow. The high energy-to-weight ratios are the main advantages of this battery technology. There is no memory effect, and a low self discharge. Therefore Li-ion batteries have high energy and power density and have been shown to be less affected by memory effect in comparison to the characteristics of other types of batteries. Portable equipment, laptops, cameras, mobile telephones, and portable tools, these are the main applications where Li-ion batteries are used. Li-ion is proving to be the most promising battery technology for plug-in hybrid and electric vehicle (EV) applications, due to its high energy density. In the Li-Ion cells the lithium is stored in, and released from a solid lattice (intercalation). The number of charge and discharge cycles are significantly increase by the help of remaining lattice structure. With higher current level, we can be able to operate the cell of this battery than other cells. But some problems have to be solved. The internal resistance can produce internal heat-up and failure. Therefore, it is mandatory to use a battery management system to at least provide overvoltage, under voltage, over temperature, and over current protection to ensure safe operation. In addition, more advanced systems provide cell voltage balancing that ensures that all batteries operate at the same voltage and, therefore, state of charge.

Lithium-ion batteries generally contain a lithium-metal oxide,

such as lithium-cobalt oxide ($LiCoO_2$). This supplies the lithium-ions. In the cathode, lithium-metal oxides are used and in the anode, lithium-carbon compounds are used. We use these materials because they allow for intercalation. Intercalation means that the molecules are able to insert something into them. In this process, lithium-ions move easily in and out of their structures is because the electrodes have the ability to do this. Inside a lithium-ion battery, oxidation-reduction (Redox) reactions take place.

- **Reduction:** At the cathode reduction takes place. There, cobalt oxide combines with lithium ions to form lithium-cobalt oxide ($LiCoO_2$). The half-reaction is:

$$CoO_2 + Li^+ + e^- \rightarrow LiCoO_2 \qquad (2)$$

- **Oxidation:** At the anode oxidation takes place. There, the graphite intercalation compound LiC_6 forms graphite (C_6) and lithium ions. The half-reaction is:

$$LiC_6 \rightarrow C_6 + Li^+ + e \qquad (3)$$

Here is the full reaction (left to right = discharging, right to left = charging):

$$LiC_6 + CoO_2 \leftrightarrow C_6 + LiCoO_2 \qquad (4)$$

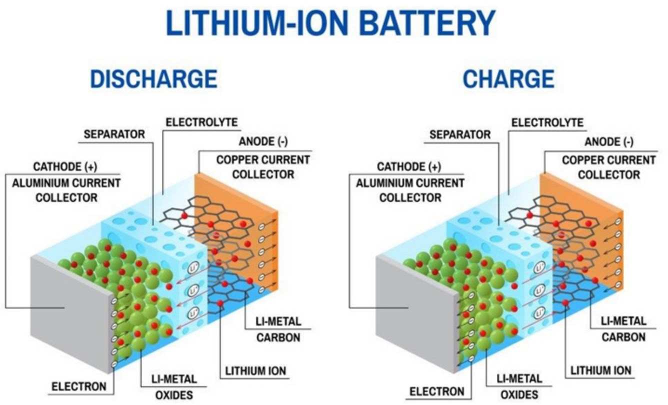

Fig.1.3: Working of Li-ion Battery

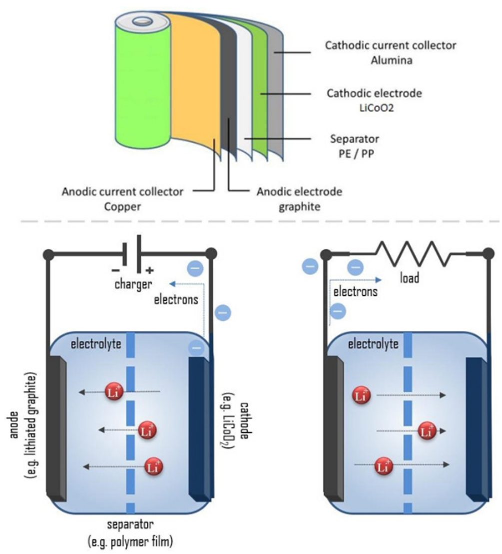

Fig.1.4: Construction of Li-ion Battery

Flywheels: It is a kind of energy conversion and storage device. We also known as electro- mechanical battery. Generally it consists of a wheel made of high strength carbon fiber, magnet floating bear supporting device, motor/generator and power electronic control device. Flywheel is supported by magnet floating bear in vacuum and converts electric energy into kinetic energy and also kinetic energy into electric energy through the same motor/generator. Flywheels store energy as kinetic energy in a rotor that is spinning at extremely high velocities. The kinetic energy of a rotating flywheel is derived as

$$E = \tfrac{1}{2} I \omega^2 \text{ and } I = \tfrac{1}{2} Mr^2 \qquad (5)$$

Where,
E is the kinetic energy stored in the flywheel I is the moment of inertia
ω is the rotational speed of the flywheel rotor r is the radius of the rotor
M is the mass of the rotor

Based on the above equation, we can be able to improve the energy storage capability of flywheels, either by increasing the moment of inertia of the flywheel, or by increasing rotational velocities. For automotive applications, higher rotational speed flywheels seem

more attractive due to the smaller size and as because of the square of its rotational speed the stored energy increases. A flywheel battery has a long life, is free from depth-of discharge effects, and can accept and deliver large amounts of energy in a very short time. The high- speed systems are more complex due to the technological requirements. But in the flywheel, the total energy stored depends on the square of the rotational speed. However, the high- speed flywheels provide higher energy density.


Fig.1.5: 3D Working of Flywheel

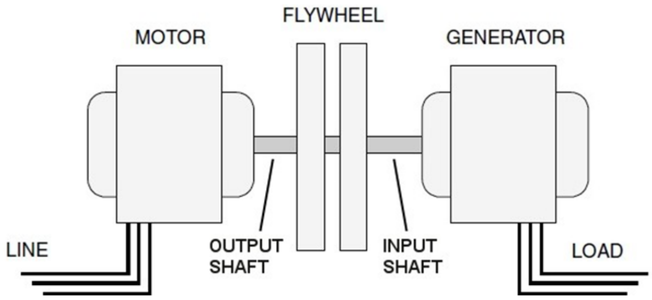

Fig.1.6: 2D Working of Flywheel

Supercapacitor/ Ultracapacitor: Super capacitor, ultracapacitors or double-layer capacitors (DLCs) as they are also known is an electrochemical capacitor. It has relatively high energy density. As compare to the conventional electrolytic capacitors, it is approximately hundreds of times greater than that. In between a pair of charged plates the energy is stored. Super capacitors comprise a significantly enlarged electrode surface area, a liquid electrolyte and a polymer membrane as compare to the conventional capacitor. Apart from that, a great advantage over batteries also offers from supercapacitor, such as the ability to be charged and discharged continuously without degrading. Supercapacitor are making the very attractive to be used in many applications is because of high efficiency and long lifecycle. Usually, super

capacitors are used for starting engines, actuators, and in electric/hybrid-electric vehicles. It is also used for transient load leveling and regenerating the energy of braking in the EVs. The super capacitor can be utilizing for regenerative breaking, which gives a great improvement in vehicle fuel efficiency under stop-and-go urban driving conditions. In the future, we can expect that ultracapacitor will become a major dominating technology in vehicle electrification. However; it is a major concern that desired energy density at reasonable weight and cost. The application of ultracapacitor in vehicle electrification is under development and significant improvement has to be done for achieving maturity and commercialization in mass scale.

The dual side of the ultracapacitor is covered with electrodes. The electrodes created with the graphite carbon. Both electrodes keep apart from each other by a permeable paper film separator. The paper separator and carbon conductors both are permeated with the fluid electrolyte with an aluminum foil. The dual coating structure of the carbon conductors and partition can be shrill but when looped with each other their operative area is into 1000 of meters squared. For enhancement of capacitance of ultracapacitor, we have to improve the area, without varying the dimensions of the capacitor. This type of capacitor stores a huge amount of charges because of it capacitance values, it is very large about 100 of farad. And fewer distances among plates, which also has a larger area to accumulate charges. This structure efficiently makes two capacitors. One capacitor at every carbon electrode provides this capacitor another name which is double layer capacitor. The voltage at the capacitor can be very less as the evaluated voltage of the ultracapacitor is calculated mostly by the breakdown voltage of the dielectric, is because of the problem occur with this trivial magnitude. Then a typical capacitor cell has a working voltage of from one to three volts, depending on the electrolyte used, which can limit the amount of electrical energy it can store. For the storing of large amount charges, the capacitor should be attached in series.

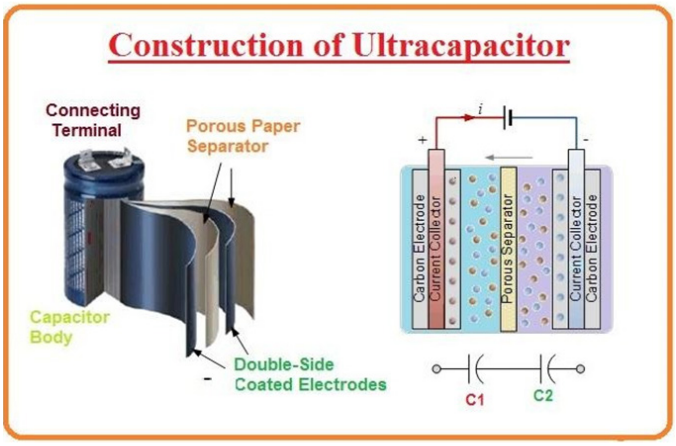

Fig.1.7: Construction of Ultracapacitor

Working of ultracapacitor

As we discussed in construction that this capacitor has two carbon films which are separated with the insulating material. The dimension of this carbon sheet is such that it provides a larger area for charge storage. The extremely permeable carbon can stored up a larger amount of energy than any other material capacitor. When the voltage provided at the +ve terminal it gets -ve inos toward them and voltage at the negative terminal attracts +ve ions toward them. This attraction makes a dual layer of coating of ions on both sides of the plate. It is named as Double-layer creation. Due to this cause this capacitor also known as dual-layer capacitor. The ions are then stored near the outward of carbon. Ultra-capacitor can store energy by static charges on opposite outsides of the electrical dual film. For the energy storing substance they use the higher area of carbon, which causes higher energy storage than other normal capacitors. The persistence of having partition is to stop the charges stirring around the electrodes. The quantity of energy stored is very large as related to the typical capacitor.

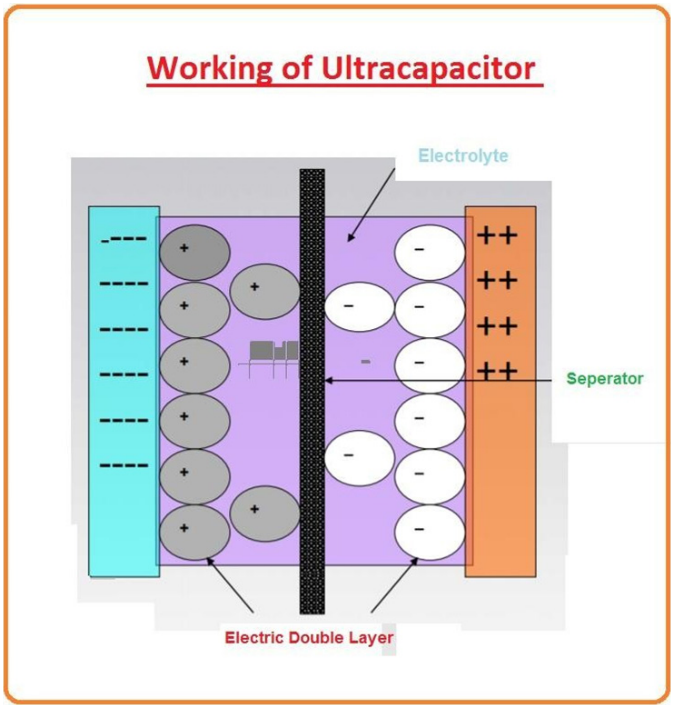

Fig.1.8: Working of Ultracapacitor

There are now four types of electric cars: battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), conventional hybrid electric vehicles (HEVs), and fuel-cell electric vehicles (FCEVs).

3. APPLICATIONS OF ENERGY STORAGE IN HYBRID ELECTRIC VEHICLES:

Battery Electric Vehicles (BEVs): BEV is commonly known as Battery Electric Vehicle. A BEV fully runs on a battery and it's working on electric drive train system. That means its delivering power from battery and gives it to the wheels. And this whole process is going on without an IC (Internal combustion) engine. These vehicles requires to recharge their batteries, for that they must be plugged these vehicles into the external source of electricity. Nowadays all EV uses regenerative braking system to recharge their batteries. BEVs also can recharge their battery using regenerative braking system. In this system, electric motor of the vehicle helps to slowing and normally regains some of the energy which is converted to heat by the brakes. BEVs are one of the EV which has zero emissions, because they do not produce any harmful tailpipe emissions or air pollution hazards as traditional gasoline- powered vehicles.

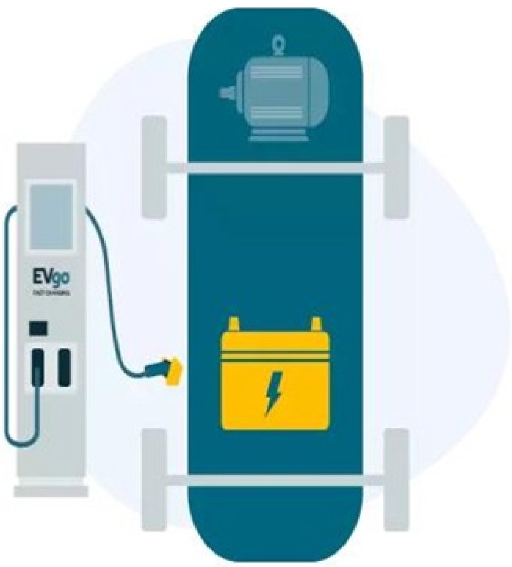

Fig.2.1: Operating Model of BEVs

Fig.2.2: BEVs on Road

Plug-in Hybrid Electric Vehicles (PHEVs): Plug-in Hybrid Electric Vehicles is generally termed as PHEV. PHEVs often run on batteries. And these batteries are recharged from the power grid. PHEVs are also furnished with an internal combustion engine, which helps to recharge the battery. And this can helps to replace the electric drive train when the battery is low and more power is required. In the PHEVs, there are IC engine and electric motor both are present to rotate the wheels. Batteries in the PHEVs, are charged from regenerative braking energy, external charging, and by the IC engine which is connected through the generator. PHEVs are consists of a much larger battery, and it can be able to plug into the grid to recharge. This thing differentiates between the regular hybrids and PHEVs. The regular hybrids can travel 1-2 miles at low speed before the gasoline engine turns on, but in case of PHEVs, it can go anywhere from 10-40 miles before their gasoline engine provide support. Once the battery is fully drained, PHEVs act as regular hybrids, and can travel several hundred miles on a tank of gasoline.

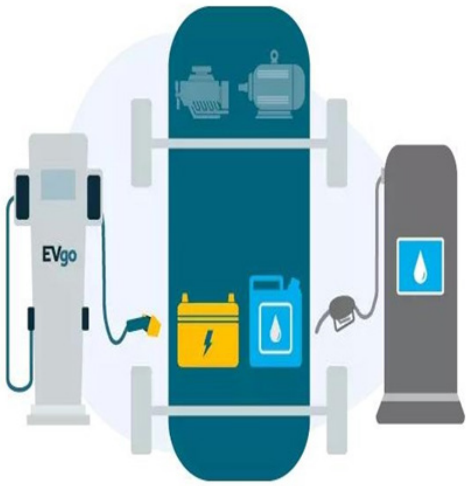

Fig.2.3: Operating Model of PHEVs

Fig.2.4: PHEVs on Road

Hybrid electric vehicles (HEVs): HEVs are called as Hybrid Electric Vehicles. HEVs have two complementary drive systems: a gasoline engine with a fuel tank and an electric motor with a battery, and controls. The engine and the motor can together turn on the transmission, which provide the powers to the wheels. HEVs cannot be recharged from the power grid. Their energy comes entirely from gasoline and regenerative braking. HEVs can be classified by their three mechanical connections. The connections are parallel, series, or parallel/ series. In parallel HEVs, the electric motor and the engine both can directly provide the power to the drive train. In a series HEV, all the propulsion power comes from the electric motor. Here the engine is used only to recharge the energy storage unit. HEVs can be either mild or full hybrids.

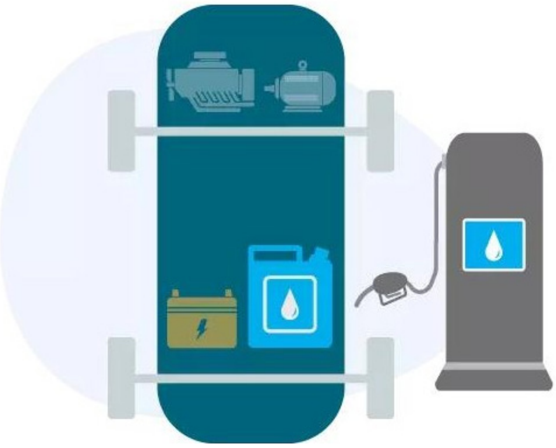

Fig.2.5: Operating Model of HEVs

Fig.2.6: HEVs on Road

Fuel-cell electric vehicles (FCEVs): Fuel-cell electric vehicles which commonly known as FCEVs. It uses a fuel cell to power the electric motor. The fuel-cell electric vehicles create electricity from hydrogen and oxygen. Internally hydrogen and oxygen chemically mixed

together and produces water. This is a zero emission vehicle, because they do not produce any harmful tailpipe emissions or air pollution hazards. According to Some experts these cars is to be the best electric vehicles. But they are still in development phases. This vehicles industry requires hydrogen refueling infrastructure, which would take a huge investment cost to set up. To make marketable and mass production of FCEVs in the future will depend on the technology. Whether there will be a technological innovation in fuel cell technology.

Fig.2.7: Operating Model of FCEVs

The hydrogen-powered Toyota Mirai at the 2019 Canadian International Auto Show.

Fig.2.8 :Real time Operating Model of FCEVs

4. ISSUES IN DEPLOYING ENERGY STORAGE SYSTEM

Issues related to energy storage technologies can be described as follows:

- ***Regulations and utility processes that disfavor energy storage:***
  1. Electricity tariffs, which are regulated by the government. The tariffs generally do not provide clear regulations on calculating the value of the energy savings offered by energy storage.
  2. No explicit mechanism to restore the value of electricity from energy storage. And this make the current rate forming process not ready for this technology.

- ***Costs:***
  1. The fact is that storage system returns less power to

the grid, which is less than the stored power. So, it will increase their cost over from the grid rate.
2. The owner/ investors generally need to look for grant from the authorities to make adjustments in electricity tariffs. However, the main cause of energy storage technologies is benefits which are usually not in parallel with the capital cost. So it is being less desirable by the investor.
3. In addition, in present time there is the lack of methodology to measure savings and the lack of arrangement of enthusiasm to prevent them from considering that the energy storage as an alternative way rather than build a new transmission lines and power plants which may be more costly.
4. In addition, while the cost of some energy storage are declining due to their mass production; then it is still comparatively too costly due their modernity and high cost of resources and the lack of large scale production.
5. The relatively high cost of some technologies compare to conventional technologies with similar power capabilities make it more difficult to attract financing although it offer free carbon.
6. The option of less expensive energy storage such as pumped hydro are obstruct by allowing or sitting challenges resulting in extra cost.

- ***Lack of awareness of energy storage benefits:***
  1. Energy storage has existed since 1970s and set to be green technology in the future, policy maker still unaware of what energy storage are and what benefits get from storage technology.
  2. No experience in spreading out the energy storage in large scale. So it makes the policy maker lack an ultimate data about the cost and energy saving capability of the technology.

- The solutions of the above mentioned should be taken by:
  1. Developing new rules and regulations to fully capture the value of energy storage and encourage the developers to invest in storage facilities.
  2. Developing tax incentives, government support for funding, and streamlined official approvals which make the technology more attractive to investors.
  3. Providing the data, perform studies and promote the findings to the policy maker, which will make them realize how important energy storage in the future.

V. CONCLUSION

The system performance has been increased as the uses of Energy Storage devices increase. A mode of storing excess energy to use it during the peak time is equivalent and more implacable than building a new power plant. Long with that, use of renewable energy has improved the environmental degradation by reducing the carbon emission from fossil fuel. However to meet the ideal characteristics of these energy storage system, more research work and study is necessary, which will replace the need of fossil fuel in the electricity network and the transportation sector.

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